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Implementation conditions for energy saving technologies and practices in office buildings: Part 2. Double glazing windows, heating and air-conditioning

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A B S T R A C T

This paper provides a review of the energy saving policies and technologies on double glazing windows, central heating and air conditioning in office buildings. After which results of a face to face survey of 685 companies' managers are presented, which give insights into the facts that have influenced them to invest in the installation of double glazing windows, installation of thermostatic regulators, inverter air-conditioning technologies and on proper maintenance and filter cleaning of the air-conditioning units. Finally, their willingness to install such technologies after a technico-economic information session is elicited. The results show that among factors that make managers have a more energy saving profile are ownership, awareness status, recent establishment of the company and companies dealing with trade. Among factors that influence willingness to undertake specific energy efficient measures for heating and cooling appear to be ownership, recently established companies, companies dealing with services, companies with a high number of personnel, and companies with high ratios of electricity bill per annual turnover.

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1. Introduction

Energy saving for buildings is a high priority for EU member states [1]. It is recognized that should be given attention to the, so long limited studied, non domestic building stock [2–4]. Design of office and public buildings, which involves physical ventilation, can lower energy consumption [5]. Also considerable savings can be achieved if requirement capacity is revisited and have oversized units replaced [6,7]. Nevertheless there is some relation between the indoor thermal comfort and energy consumption [8–10]. Apart from the above mentioned measures specific actions can be addressed at construction or retrofitting stage, considering cost analysis for the selection of appropriate equipment. Here follows a discussion for the main topics covered in this paper, i.e. double glazing and heating – air conditioning.

1.1. Double glazing windows

Buildings which have a well insulated outer envelope and well optimized glazed windows have lower energy consumption, since heating and cooling loses are less [11–13]. Heat losses from windows are the greatest amount of the total heat loss of a building [14–16]. The use of improved energy saving double glazing windows can contribute considerably to the energy efficiency [17] for heating, cooling and lighting of buildings as well as to the improvement of thermal and acoustic comfort conditions [18] in the indoor environment [19]. Double glazed windows only have about half of the heat transfer coefficient of a single one [20]. That's why, recently, double-glazing units have become the standard type of glazing for windows in the construction of new housing and commercial buildings. This has been brought about by changes in the building regulations that have encouraged reduced heat losses through the building fabric [21]. The potential energy saving by replacement of single glazing with double glazing provides a potential energy saving equal to 39–53% according to an assessment carried out in the commercial building sector in the United Kingdom [22]. Nowadays, from ordinary plate glass, there has been expansion into energy saving glazing with the use of solar filters [23], low-e glass [24,25], photochromic glass, and electrochromic glass [26].

Heat-insulation regulation for buildings has been in force in Greece since 1979 [27], where the use of double glazing in new buildings is obligatory so as to meet the EU regulation requirements. For the old buildings, built mainly before 1979, the replacement of single-pane windows with double-pane, with potential replacement also of window frames constitutes an important energy saving technique. The replacement of old window frames with new energy efficient ones, although a relatively high capital cost, can improve to a significant extent the energy performance of the building, and it also has multiple environmental and economic benefits.

1.2. Heating and air conditioning

The European Union, adopted measures for energy efficiency concerning space heating and insulation early on. This was enacted with the Council Directive 78/170/EEC [28] regarding the performance of heat generators for space heating and the production of hot water in new or existing non-industrial buildings and insulation of heat and domestic hot-water distribution in new non-industrial buildings, as well as, energy efficiency for hot-water boilers [29]. The updated provisions of the above directives together with the relevant legislation have been integrated into the recent "Energy Performance of Buildings" Directive 2002/91/EC [30].

During the period of heating, heating is about 40% of the total consumed energy in a building [20]. The use of automatic controllers helps save energy while keeping occupants' comfortable [31]. Balaras et al. [32] reported that 11% of space heating can be saved annually through the maintenance of central heating installations.

The number of central air-conditioning systems installed in buildings has increased by a factor of 4.5 in the last 20 years in Europe [33]. Heating Ventilation and Air Conditioning (HVAC) consumption in developed countries accounts for half the energy use in buildings [34]. According to a survey for the island of Crete [35], the number of split units was estimated at around 587,000 while about 12,500 were central cooling systems. A reduction in the energy consumed for cooling in office buildings can be achieved by improving the building envelope, using alternative cooling techniques or by using more efficient air-conditioning systems [36,37]. Mortimer et al. [22] reported that the installation of units with improved design and control air conditioning systems could potentially provide a 20% energy saving. Energy saving can also be achieved by effectively adjusting the temperature set point [38] and using optimal control techniques [39].

In terms of central air conditioning (A/C) there is energy wastage, which can be treated with specific information on A/C operation and maintenance [40]. Scrase [41] defined "good" and "typical" energy practices in offices in the UK, in terms of cooling energy consumption, with "good" being about half of them. Knowledge of individuals is needed to identify and implement the best technical solution for environmentally sustainable buildings [42]. Lack of information on energy costs and benefits [43,44] and non-ownership of buildings appears to be the main barriers for energy saving technology intrusion [41]. Specific public/market information on the operation and maintenance of A/C makes individuals empowered to make informed decisions that affect energy efficiency [40,45,46]. The use of eco-labeling promoted also by government initiatives has wide implications for consumers and companies, affecting the purchasing process for product selection [47].

2. Research methodology

In this second part of the paper the results of the double glazing windows, central heating and air conditioning energy saving technologies in office buildings are presented [48]. The first part [49] presents results for the lighting saving technologies. Data collected aimed at assessing the implementation level of selected energy efficient/saving technologies and practices and willingness to replace conventional technologies with energy saving ones for window glazing, central heating and A/C and also willingness to undertake actions that lead to energy saving like regular maintenance of heating and A/C units. Modeling of the revealed and stated preferences shortlisted those variables that make people invest in double glazing windows, thermostatic regulators, inverter A/C, regular maintenance of A/C units and regular A/C filter cleaning.

2.1. Double glazing windows

The first question in the questionnaire concerning the double glazing windows recorded the glass surface of the office in square meters. If the respondent could not provide a value the interviewer measured the dimensions of the windows. Afterwards, whether they had double glazing was recorded. In order to find out what makes people install the double glazing windows a binary model was estimated with Y_1 the dependent variable, which was assigned "1" if respondents had installed double glazing windows and "0" if they had not.

Those who did not have double glazing windows were provided with the following information session: "The installation of

double glazing windows costs 28 €/m^2 (for materials and installation work) and can provide energy savings of up to 35%. For oil central heating systems the annual energy saving is equivalent to 4€ per year for 10 m^2 of windows, and the cost would be paid back in 9 years. For offices heated and cooled with air-conditioning, energy savings can be equivalent to 5.5€ per year for 10 m^2 of windows, and the payback period is estimated at 6.5 years. These typical figures are reported for buildings with 15% openings of their total area." During the information session, a card with thermographs depicting the difference in thermic profiles for a room with single glazing and one with double glazing was shown to the respondents. Then these respondents were asked "Would you install double glazing windows if this was going to cost you ... (# of m^2 × 28€ =) ...€ with a payback period of 6.5/9 years?". These calculations were carried out in the presence of the respondent. A "Yes" or "No" option was given. In order to find out variables that make people willing to install double glazing windows, a binary regression model with Y_2 being the dependent variable of their statement was estimated.

2.2. Heating

In the following section of the questionnaire, respondents were asked to report which was or were the means of heating in their offices. The following options were given: oil (central heating system), oil stove, electric halogen stove, air conditioning, liquefied petroleum gas stove, electric heating, electric hot air fan, and central heating with combustion of olive kernel wood. Then, those with central heating were asked to state the age of the system. Next, they were asked if they performed an annual maintenance service of the oil boiler-burner. In order to find out what makes people have their oil boiler-burner serviced regularly a binary model was designed to be estimated with a dependent variable, which was assigned "1" if the respondent performs regular annual maintenance of the boiler-burner and "0" if they did not. Then, the respondents were asked how much they pay for oil consumption per year.

Those who did not perform an annual maintenance service were provided with the following information session: "The total cost (for the building) of the, annual maintenance of the central heating system, which is compulsory by law, is 150–200€ (40–60€ per flat or per detached house). By doing so, you have a 10–15% energy saving and better performance of the heating system which extends its operational life. One typical flat of 100 m^2, with 8 h of operation recovers this amount (i.e. the 40–60€) and on top of that it saves at least this amount, compared to one that is not maintained" [50]. During the information session respondents were shown photos of a typical central heating system. Then, these respondents were asked "Would you have your central heating system maintained annually?". A "Yes" or "No" option was given.

Next, respondents were asked if they had installed thermostatic regulators on their radiators. In order to find out what makes people install the thermostatic regulators a binary model was estimated with a dependent variable Y_3, which was assigned "1" if the respondent had installed thermostatic regulators and "0" if they had not. Then, for those who had not installed a thermostatic regulator, an information section followed stating the following: "*Thermostatic regulators of radiators cost 20€ each, including the installation cost. A 10% energy saving is achieved and the cost would be recovered in 1.5 years*" [50]. A card with a photo of different types of thermostatic regulators was shown to the respondent at the same time. After which, the following question was asked "*Are you going to install thermostatic regulators to the heating units if they are going to cost you* ...(# of units × cost per unit=) ...*€?*". These calculations were carried out in the presence of the respondent. A "Yes" or "No" response option was given. In order to find out variables (drivers) that make people willing to install thermostatic regulators, their response was modeled with a binary regression model with Y_4 being the dependent variable of their statement.

2.3. Air conditioning

Firstly, whether the office had A/C was recorded and those who did have it were asked how many air conditioning units were in the office and the total cooling power in KW or BTU. They were also asked how many years ago their air conditioning units were installed. Then, they were asked if they knew about inverter technology and its high energy efficiency. After which they were asked if they knew that A/C units were classified into energy efficiency classes. If they gave a positive response they were asked to state the energy class of their air-conditioning units. Next respondents were asked whether they had an inverter air conditioning unit. A "Yes" or "No" response option was given. In order to discover which variables make people invest in energy saving inverter technology, their response was modeled with Y_5 being the dependent variable of their statement.

Then those who had not installed an inverter technology unit were provided with the following information session: "*The use of inverter technology – Class A – energy category of* air conditioning units *can save up to 55% of the energy and costs on average 230€ more (+25%). The pay back period is estimated at 3 years saving about 70€ per year in energy compared to a conventional – Class D – cooling system*" [50]. A card with a photo of the energy classification system for air conditioning units was also shown to the respondent at the same time. Then the following question was asked "*Are you going to install inverter technology units on your next purchase?*". A "Yes" or "No" response option was given. In order to find out which variables make people willing to buy inverter technology, their response was modeled with Y_6 being the dependent variable of their statement.

Next respondents were asked how often they have their air-conditioning units maintained by technicians, the following options were coded: less than once per 4 years, once every 2 or 3 years, once per year, and once per semester. This question was designed to investigate the frequency of maintenance (Y_7) and in order to find variables that explain this, an ordinal regression was estimated. Those that did not have at least an annual maintenance of their air conditioning units, were provided with the following information session: "*The annual maintenance of an* air conditioning unit *costs 30€ and this results in 10–15% energy saving due to more efficient operation and in the extension of the operational life of the device. This cost depreciates over a year*". Then the following question was asked "*Are you going to have your air conditioning units maintained annually?*". A "Yes" or "No" option was given. In order to find out which variables make people willing to have their A/C units maintained regularly, their response was modeled with a binary regression model with Y_8 being the dependent variable of their statement.

Then respondents were asked how often they have had the filter in their air conditioning unit cleaned or how often they have cleaned it themselves; the following options were coded: less than once per 4 years, once every 3 or 4 years, once per year or every 2 years, and at least once per semester. This question was asked to investigate how often the filters were cleaned (Y_9) and in order to find variables that explain this, an ordinal regression was estimated. Those that did not perform a 6 month filter cleaning of their air condition units were provided with the following information session: "*Cleaning (even yourself) with removal-washing-replacement of the A/C filter improves significantly the air quality of the filtered air and saves 5% energy which is equivalent to 9–10€ saving per year.*" Then the following question was asked "*Are you going to have your air-condition filters maintained* or maintain

Table 1
Summary of the regression models.

Dependent variable	Description of dependent variable	Values	Regression type
Y_1	Have installed double glazing windows	1: Yes, 0: No	Binary
Y_2	Willingness to install double glazing windows	1: Yes, 0: No	Binary
Y_3	Have installed thermostatic regulators	1: Yes, 0: No	Binary
Y_4	Willingness to install thermostatic regulators in all radiators	1: Yes, 0: No	Binary
Y_5	Have selected inverter air-conditioning technology	1: Yes, 0: No	Binary
Y_6	Willingness to install inverter air-conditioning technology in the next purchase	1: Yes, 0: No	Binary
Y_7	Frequency of air conditioning units maintenance by a technician	1: Once every 4 years or less 2: once every 2 or 3 years 3: once per year 4: at least once per semester	Ordinal
Y_8	Willingness to have maintenance of air-conditioning units with technician annually if not already, if not already undertaken	1: Yes, 0: No	Binary
Y_9	Frequency of filter cleaning of air-conditioning units	1: Less than once per 4 years 2: once every 3 or 4 years 3: once per year or every 2 years 4: at least once per semester	Ordinal
Y_{10}	Willingness to clean or have the air-conditioning filter cleaned at least once per 6 months, if not already undertaken	1: Yes, 0: No	Binary

them *annually?*". A "Yes" or "No" response option was given. In order to find out which variables make people willing to have their filters maintained regularly or to maintain them themselves, their response was modeled with a binary regression model with Y_{10} being the dependent variable of their statement. Finally, in order to find out if there are more cooling options, the respondents were asked to state if there were any table or roof fans in the office.

All cost figures were calculated for the climatic and market conditions of Crete and were referred to the period the data collection was implemented [50]. A summary of the models estimated in this paper are presented in Table 1.

3. Results and discussion

In this section diachronic development of heating and cooling in office buildings in major towns of Crete and descriptive statistics are presented before discussing the estimated models of this paper.

3.1. Heating and cooling status in Crete

Heating energy efficiency has not been given much attention in Crete because it is a Southern European area with short winter and relatively low demand for heating oil. Table 2 presents the means of heating used in office buildings. Some offices have more than one heating mode.

The installation year for those who have oil central heating is given in Fig. 1. It can be seen that oil central heating was initially installed in the early 1970s and during 2006 30% of the office buildings examined were heated by central oil heating. Although air condition is also reported as a means of heating it should be mentioned that this is mainly installed for cooling, and is used for heating only as a supplementary means.

Only 84 offices (12.26%) had not installed an air cooling system, while 252 (36.79%) had installed just one. Two cooling units were installed in 200 offices (29.20%) and three in 102 offices (14.89%). There was one office with 13, one with 15 and one with 20 cooling units. The office area and personnel statistics per air condition unit are shown in Table 3. On average an office with 2 units would correspond to an area of 65.1 m^2 and 2.4 personnel, while an office with 3 units would correspond to an area of 88.9 m^2 and 3.1 personnel.

The increase in living standards during recent years goes hand in hand with an increased level of indoor thermal environment,

Table 2
Heating practices in the offices.

Heating mean	*n*	%
Oil (central heating system)	208	30.4
Oil stove	5	0.7
Electric halogen stove	34	5.0
Air conditioning	597	87.2
Liquefied petroleum gas stove	3	0.4
Electric heating	26	3.8
Electric hot air fan	32	4.7
Central heating with combustion of olive kernel wood	1	0.1

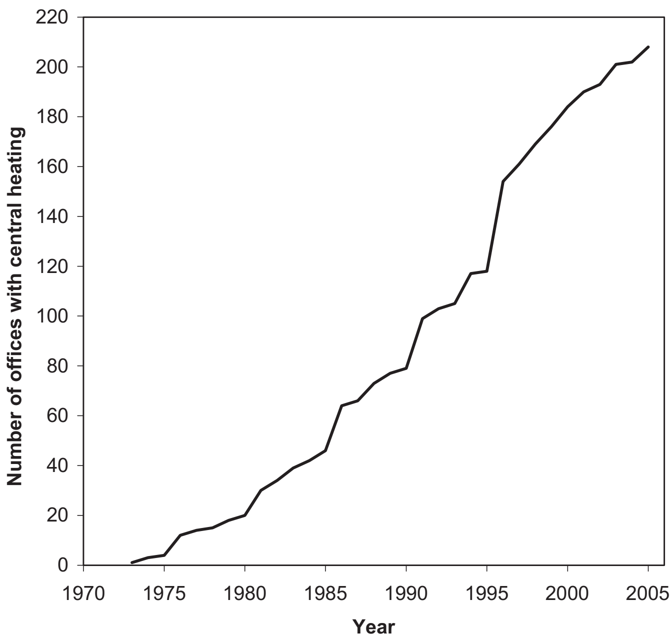

Fig. 1. Diachronic increase in the number of central oil heating installed.

especially during winter. On the other hand, recently there was a massive use of A/C units, especially during summer, for building cooling. The drop in price of A/C units, the increase in living standards, the low price of electricity, the massive seasonal tourism during the summer months, are the most important reasons which explain the explosive expansion in the use of air-conditioning in southern climates. It has to be underlined that this massive intrusion of air conditioning, the very low promotion of energy efficient units (energy labeling) by the sellers and the absence of continuous and targeted awareness campaigns on A/C efficient use is the main cause of the electricity power shortages and the poor quality of electricity provided during the summer peak demand hours. This situation indicates the need in the reinforcement of the supply capacity of the autonomous electricity system of Crete. A program replacing old A/C units with A′ class and inverter technology A/C units in the domestic sector was implemented by the Greek Ministry for Development. The financial incentive per household was up to 500€ subsidy once the inverter A/C units are purchased followed by the withdrawal of the old A/C. The program was very successful [51]. Financial incentives have been widely used for promoting purchasing of energy saving technologies [52]. According to the Regional Energy Agency of Crete, in 2006 the additional power during the peak demand due to the newly installed A/C units every year in Crete has reached 30 MW during the past 4 years [50].

Only 80 of the respondents (13.33%) were able to provide the energy class of the cooling units for the company they manage. The most probable is that the purchase took place recently. From those 42 (52.5%) had purchased an A class unit. The responses of this question are given in Table 4.

The diachronic installation of inverter units in comparison to the total installed are shown in Fig. 2. It can be observed that it follows the same trend profile as the number of central oil heating installed. Just 36 (5%) and 14 (2%) of the offices had installed table-floor fans or roof fans respectively.

Table 3
Office area and personnel statistics per air conditioning unit.

A/C units	N	Office area (m^2)				Personnel			
		Min	Max	Mean	SD	Min	Max	Mean	SD
0	84	15	250	62.4	50.9	1	9	2.5	1.8
1	252	13	1800	63.4	131.6	1	92	2.6	5.9
2	200	30	250	65.1	29.0	1	16	2.4	2.0
3	102	35	300	88.9	39.7	1	10	3.1	1.6
4	26	60	250	117.3	47.4	1	8	4.0	1.9
5	10	90	160	124.0	22.7	2	12	5.9	2.7
>5	11	120	2000	464.6	527.6	4	27	13.1	6.4

SD, standard deviation.

Table 4
Knowledge of the energy class of the office air cooling system.

Energy class	Number	Valid percent (%)	Overall percent (%)
A	42	52.5	6.99
B	11	13.8	1.83
C	1	1.3	0.17
D	14	17.5	2.33
E	7	8.8	1.16
F	3	3.8	0.50
G	2	2.5	0.33
Sum	80		13.3
Do not know	521		86.7
Total	601	100	100

3.2. Descriptive statistics

Statistically significant variables at 5% level were kept in the models Y_1–Y_{10}. They have been grouped into: building envelope, electricity, A/C and heating, business and respondent related variables as described in Table 5, followed by their mean value and standard deviation.

Discussion of some variables has already been presented in Part 1 paper [49]. 30% of the offices examined were owned. The average electricity bill was 182.69€ quarterly. The mean quarterly electricity bill for offices with A/C was 187.0€ compared to 151.43€ for those offices that did not have A/C. On average the offices with A/C units had 18591 BTU cooling capacity installed. The average period A/C had been installed was 5.17 years, while for central heating it was 14.27 years. Only in 8.6% of the total offices examined had A/C with inverter technology been installed. The annual cost of oil used for heating was 125.77€, per company on average. The average age of the

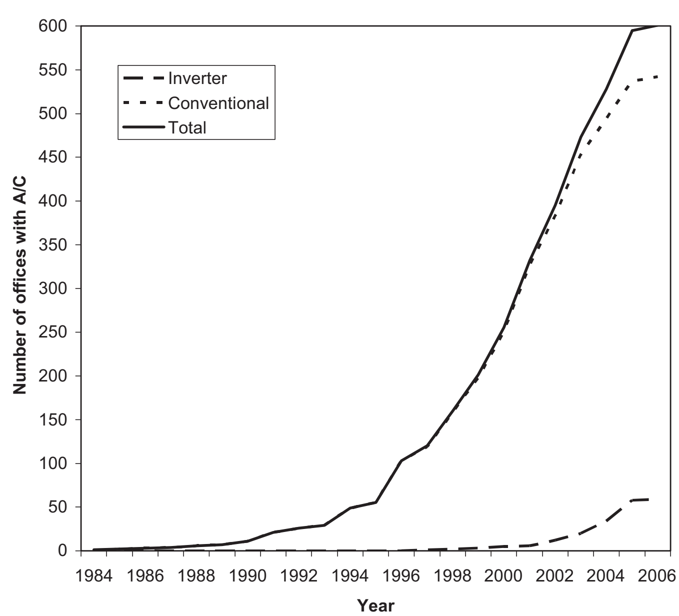

Fig. 2. Diachronic installation of inverter units in comparison with the total number of A/C.

Table 5
List of variables and descriptive statistics for variables of models Y_1–Y_{10} (n = 685).

Variable	Description	Mean	Standard deviation
Building envelope			
PR	Owned or rent facilities: 1 = Owned, 0 = Rent	0.300	0.458
SM	Square meters of the floor area of office facilities	76.98	118.22
Y1	Year the building was constructed: 1 = Before 1980, 0 = Otherwise	0.222	0.416
Y2	Year the building was constructed: 1 = 1981–1990, 0 = Otherwise	0.276	0.447
Y3[a]	Year the building was constructed: 1 = 1991–2000, 0 = Otherwise	0.324	0.468
Electricity			
BAI	Negative impacts of the electricity shortages on the company activities: 1 = Yes, 0 = No	0.690	0.461
DEI	Electricity bill (€)	182.690	219.50
A/C and heating			
BTU	Total installed BTU in the office	18,591	18,363
ACY	How long ago the air conditioning unit was installed (years)	5.170	4.049
INV	Have inverter air conditioning technology: 1 = Yes, 0 = No	0.086	0.281
HEATYR	How long ago the central heating was installed	14.270	8.042
OIL	Annual cost for oil heating (€)	125.77	267.23
Business			
SUB	Business activity: 1 = Services, 0 = Trading	0.870	0.333
L1[b]	Business form: 1 = company, 0 = Otherwise	0.808	0.395
L2	Business form: 1 = Partnership or Limited partnership, 0 = Otherwise	0.107	0.310
BAL	Turnover for the year 2005 (€)	162,838	329,032
PER	Number of personnel	2.880	4.182
OLD	Number of years in operation	13.450	10.204
Respondent			
AGE	Age of the respondent	41.980	10.318
ATT	Aware that significant energy savings can be made through the appropriate behavior? 1 = Yes, 0 = No	0.860	0.343
INFO	Informed about energy saving: 0 = Not informed, 1 = Informed	0.472	0.500
INVINF	Informed about A/C inverter technology: 1 = Yes, 0 = No	0.413	0.491
CKN	Informed about A/C energy classification: 1 = Yes, 0 = No	0.404	0.491
NT	Aware that they can save energy with the use of new technology and appliances: 1 = Yes, 0 = No	0.750	0.413
SAVE	Energy saving should come before new investments for energy production: 1 = Agree, 0 = Disagree or neutral	0.710	0.456

[a] The reference category is 2001–2005.
[b] The reference category is Incorporation or Limited Liability Company.

companies was 13.45 year. Informed about A/C inverter technology and A/C energy classification claimed to be 41.3% and 40.4% of the managers interviewed. Energy saving should come before new investments for energy production according to 71% of the managers.

3.3. *Has installed double glazing windows and willingness to install double glazing windows*

Out of 685 offices 367(53.6%) had installed double glazing windows. From those who had not, 113 stated that they were willing to do so, after the information session, while the rest were not (Fig. 3).

Results for model Y_1 are presented in the left panel of Table 6. Owned offices (PR) had a higher probability of having double glazing windows than rented ones ($\widehat{\beta} = 0.725$, $p < 0.001$). This is something expected [53] since those owners of buildings who are going to rent their offices do not install the double glazing windows due to the increased capital cost. No matter if the tenant has to pay in the long run this cost in energy bills. Tenants are discouraged from undertaking this energy saving intervention as it requires a long pay back period and it is not possible to take it with you when leaving the property as you could do, for example, with an electrical heater or even an air-conditioning device. The earlier the office was constructed, the less probable it was for double glazing windows to have been installed (Y). This is something

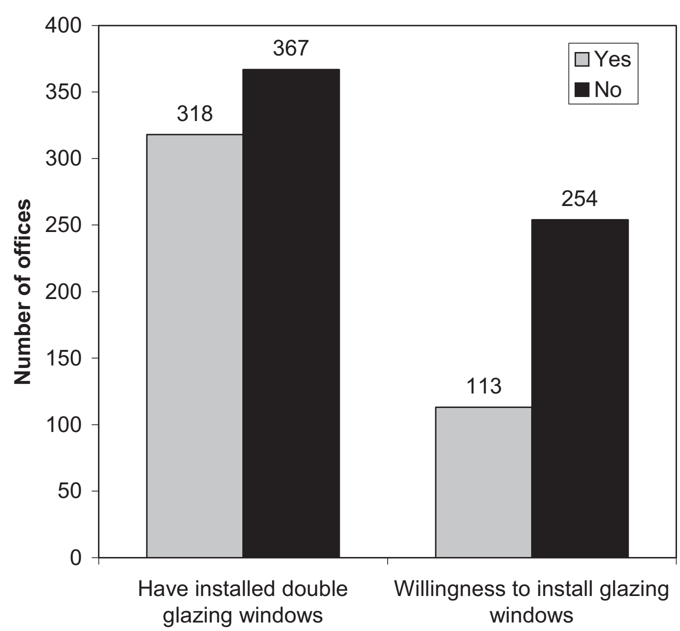

Fig. 3. Have installed and willingness to install double glazing windows.

Table 6
Results for models Y_1 and Y_2.

Variables and statistics	Model Y_1 (n = 685)			Model Y_2 (n = 367)		
	$\widehat{\beta}$	Wald χ^2	p	$\widehat{\beta}$	Wald χ^2	p
C	−1.710	12.474	<0.001	−0.321	1.342	0.247
Y		37.707	<0.001			
Y1	−1.528	29.107	<0.001			
Y2	−1.265	23.529	<0.001			
Y3	−0.544	4.986	0.026			
L		14.314	0.001			
L1	0.862	10.877	0.001			
L2	−0.500	0.567	0.451			
PR	0.725	16.193	<0.001	1.394	24.967	<0.001
ATT	0.703	8.058	0.005			
AGE	0.018	4.308	0.038			
BAL	8.019×10^{-7}	7.877	0.005	-1.067×10^{-6}	2.853	0.001
NT				−0.568	4.766	0.029
OLD				−0.023	2.981	0.004
Pseudo R^2		0.150			0.127	
−2 LL		864.369			418.460	
Hosmer and Lemeshow test		7.211	0.514		6.768	0.562
Overall predictive accuracy		63.6%			70%	

expected, since heat insulation was first enacted in 1979 [54], while it started spreading in the Greek market during the 1990s. Initially, more emphasis was placed on the insulation of thermal elements, while the installation of double glazing windows was regarded as a luxury at that time. During the last years, however, consumers have started considering double glazing windows as a basic feature of a building, since they provide thermal and sound insulation. Double glass intrusion was aided, also, by technology advances, which involves aluminum, plastic and advanced wooden window frames. Since the reference category is offices constructed after 2000, the negative sign of predictors for variables Y1, Y2 and Y3 indicates that recently constructed offices have a higher probability of having installed double glazing windows. This finding indicates that renovation subsidy polices should be aimed at early constructed buildings. Private companies (L1), mainly small enterprises were more probable to have installed double glazing windows compared with limited liability companies ($\widehat{\beta} = 0.862$, p = 0.001). Companies with a higher turnover (BAL) had a higher probability of having installed double glazing windows compared to those with a lower turnover ($\widehat{\beta} = 8.019 \times 10^{-7}$, p = 0.005), as expected. Those who stated that with the appropriate behavior it is possible to save energy (ATT), were more probable to have installed double glazing windows ($\widehat{\beta} = 0.703$, p = 0.005). This is an expected finding since those people were already aware of this basic energy saving action. Managers of higher age (AGE) were more probable to have installed double glazing windows compared to the younger ones ($\widehat{\beta} = 0.018$, p = 0.038). This may seem contradictory to other studies for environmental friendly behavior [55–58] or energy related [59], but it is explained by the idiosigracy of older people in Greece (see also model W_2 of Part 1 paper [49]). 35–45 years ago electricity was not supplied to all towns and villages. At that period, electricity was a new and a "luxury" good, since the standard of living was not very high and many people were still at that time trying to get basic amenities. So, even today older people appeared to appreciate and to be more sensitive to electricity provision behaving in a more "energy wise" way than younger people. This finding is also supported by another study concerning energy from biofuels where it was also found that older people behaved more energy wise compared to younger ones [60]. In addition Martinsson et al. [61] found older people to behave more energy saving on heating compared with younger.

Results for model Y_2 are presented in the right panel of Table 6. According to responses of their managers, companies in owned offices (PR) with one pane of glass, have a higher probability to have double glazing windows installed ($\widehat{\beta} = 1.394$, p < 0.001) in the future compared with those who rent the buildings of their offices. This is an expected finding and is justified in the same way as model Y_1. Managers who claimed to know that the use of new technologies or appliances can save energy (NT), and not having installed double glasses so far, were less probable to be willing to do so now ($\widehat{\beta} = -0.568$, p = 0.029). This finding shows that those who state to know about technologies for energy saving, also know that this investment has a long payback period, and additionally it requires major building renovation. It also indicates that the information session provided for managers with a lower level of awareness had a greater effect on their energy saving behavior than the one provided for managers with a higher level of awareness. The higher the turnover of the company (BAL) the lower their willingness to install double glazing windows ($\widehat{\beta} = -1.067 \times 10^{-6}$, p = 0.001). This variable has the opposite sign compared to model Y_1. This means that the information session had a greater effect on companies with small turnovers. The more recently a company was established (OLD) the more willing they were to install double glazing windows, compared with the older ones ($\widehat{\beta} = -0.023$, p = 0.004). This indicates that managers of recently established companies were more probable to be open to new technology and innovation.

3.4. Annual maintenance of the boiler-burner

With regards to the question about whether the boiler-burner was maintained annually, 95.19% of the respondents reported that it was (Fig. 4). This verifies findings reported by Santamouris et al. [37], who reported 95.33% annual maintenance, for another area of Greece. Although it was intended to run a binary regression to model this action, this was not possible due to the very high "Yes" response rate. For the same reason it was not possible to estimate the next statement which aimed to model the positive responses in the question "If you do not do an annual maintenance, will you do it in the future?", which was asked after the relevant information session described in the research methodology.

3.5. Have installed thermostatic regulators and willingness to install thermostatic regulators in radiators

From the 208 offices to which this question addressed (offices with central heating) 139 (66.8%) had installed thermostatic regulators. From those who had not, 53 (76.8%) stated that they would do so in the future after the information session, while 16 (23.2%)

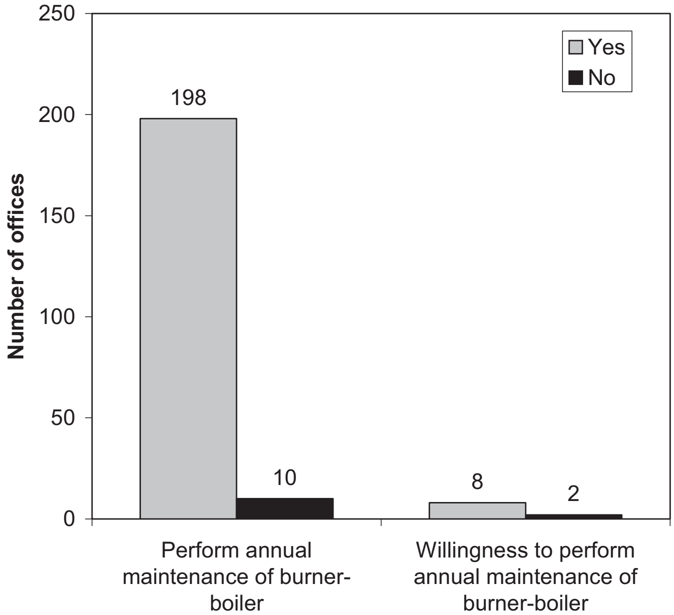

Fig. 4. Performing and willingness to perform maintenance to the burner-boiler annually.

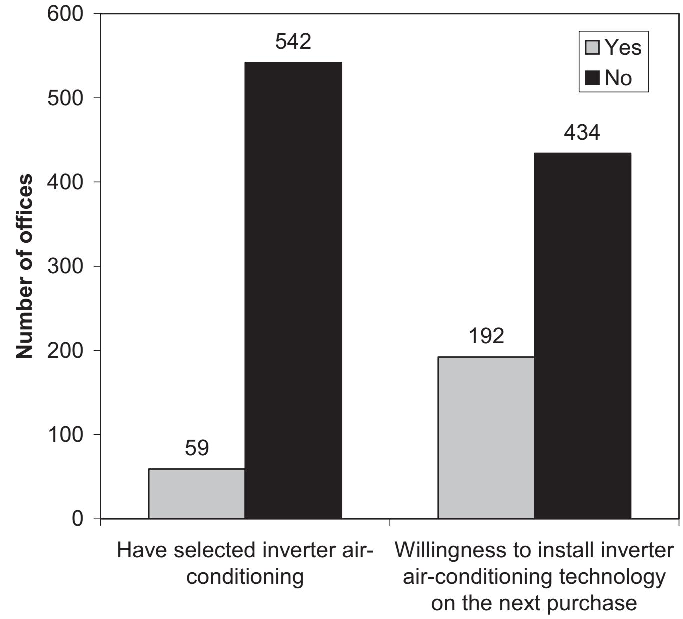

Fig. 6. Installation and willingness to install inverter air-condition technology.

stated that they would not (Fig. 5). It should be mentioned that thermostatic regulators are of very low cost, but it requires technical expertise to install them, in contrast for example, with the replacement of an incandescent lamp with an energy saving one. Additionally, there is no awareness and target information revealing their energy and cost benefits, taking also into account that Crete is a Southern area and the central heating systems for buildings has only started to be used relatively recently and that the heating period is only 4 months long.

Results for model Y_3 are presented in the left hand panel of Table 7. Ownership of the office (PR) was probable to favor the installation of thermostatic regulators ($\widehat{\beta} = 1.224$, $p = 0.001$) which is an expected result [53] in accordance with finding of models Y_1 and Y_2. Offices in which the natural logarithm of annual cost for oil (LN(OIL)) was low were more probable to have installed thermostatic regulators ($\widehat{\beta} = -0.464$, $p = 0.044$). In those offices where central heating had been installed a long time ago they (HEATYR) were less probable to have installed thermostatic regulators ($\widehat{\beta} = -0.055$, $p = 0.006$) compared to those that installed heating recently, which is an expected finding.

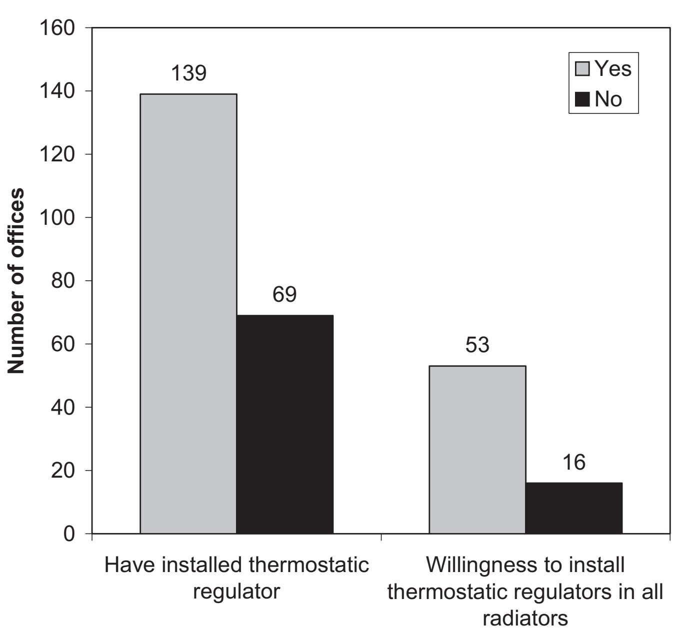

Fig. 5. Installation and willingness to install thermostatic regulators.

Results for model Y_4 are presented in the right hand panel of Table 7. Those claiming that they knew that the appropriate behavior can result in energy saving (ATT) were more probable to state that they would install thermostatic regulators ($\widehat{\beta} = 1.503$, $p = 0.041$). This finding implies that there is a lack of information on this issue, but it applies to a very small part of the surveyed companies. Partnership or limited partnership companies were on average less willing to install thermostatic regulators ($\widehat{\beta} = -3.647$, $p = 0.017$), compared to Incorporations or Limited Liability Companies.

3.6. Have selected inverter air-conditioning and willingness to install inverter air-conditioning technology on the next purchase

From the 601 offices with air conditioning, 59 (9.8%) had installed units with inverter technology. From those that had not 192 (30.7%) out of 626 (those not having air-condition were also included) questioned gave a positive answer in the question "would you install an inverter technology air conditioning unit on your next purchase?" (Fig. 6).

Results for model Y_5 are presented in the left hand panel of Table 8. Those who agreed that energy saving should precede any investment for covering the increasing energy needs (SAVE) were more probable to have installed inverter A/C ($\widehat{\beta} = 0.934$, $p = 0.040$), which is an expected finding as people with a very high level of energy awareness make energy wise decisions. Those that had installed their A/C more recently (ACY) were most probable to have selected an A/C with inverter technology ($\widehat{\beta} = -0.582$, $p < 0.001$). This is an expected finding, since inverter technology is a recent development (see also Fig. 2). Those who were aware of inverter technology (INVINF) were more probable to have installed an inverter A/C ($\widehat{\beta} = 2.052$, $p < 0.001$). Those who knew that A/C are classified according to categories in reference to their energy (class) efficiency (CKN) were more probable to have installed an inverter

Table 7
Results for models Y_3 and Y_4.

Variables and statistics	Model Y_3 ($n = 208$)			Model Y_4 ($n = 69$)		
	$\widehat{\beta}$	Wald χ^2	p	$\widehat{\beta}$	Wald χ^2	p
C	3.837	7.685	0.006	0.694	0.291	0.589
PR	1.224	10.989	0.001			
LN(OIL)	−0.464	4.053	0.044			
HEATYR	−0.055	7.483	0.006			
ATT				1.503	4.178	0.041
L					7.158	0.028
L1				−0.714	0.403	0.526
L2				−3.647	5.690	0.017
Pseudo R^2		0.140			0.273	
−2 LL		242.241			66.793	
Hosmer and Lemeshow test		8.470	0.389		0.001	0.999
Overall predictive accuracy		69.7%			78.3%	

Table 8
Results for models Y_5 and Y_6.

Variables and statistics	Model Y_5 ($n = 601$)			Model Y_6 ($n = 626$)		
	$\widehat{\beta}$	Wald χ^2	p	$\widehat{\beta}$	Wald χ^2	p
C	−3.750	16.167	<0.001	−4.224	23.661	<0.001
SAVE	0.934	4.223	0.040			
ACY	−0.582	38.879	<0.001	0.067	9.303	0.002
INVINF	2.052	20.136	<0.001	0.699	13.023	<0.001
CKN	0.950	5.889	0.015			
INFO				0.514	7.142	0.008
LN(DEI)				0.539	8.997	0.003
SM				−0.007	8.190	0.004
PR				0.630	9.641	0.002
OLD				−0.030	7.294	0.007
Pseudo R^2		0.422			0.149	
−2 LL		248.727			701.879	
Hosmer and Lemeshow test		7.005	0.536		9.589	0.295
Overall predictive accuracy		90.7%			70%	

A/C ($\widehat{\beta} = 0.950$, $p = 0.015$). All the last three variables indicate that the more informed a manager is about energy related issues; the more probable he is to make energy wise purchasing decisions. The positive effect of information on energy efficient and renewable investments have been well documented so far [62,63].

Results for model Y_6 are presented in the right hand panel of Table 8. Those companies that the natural logarithm of the electricity bill (LN(DEI)) was high were more probable to be willing to buy an inverter A/C on their next purchase ($\widehat{\beta} = 0.539$, $p = 0.003$) which is an expected finding. The companies located in larger offices (SM) were on average less willing to install inverter technology on a future purchase ($\widehat{\beta} = -0.007$, $p = 0.004$). This could be explained by the fact that large offices use many A/C units and the choice to replace them with A/C inverter units would be a considerably higher initial investment cost for them, thus the decision to replace them is more complicated than in individual office companies and smaller offices. Furthermore, in larger offices not all space is equally occupied by manpower and this can make a full

Table 9
Results for models Y_7 and Y_8.

Variables and statistics	Model Y_7 ($n = 601$)			Model Y_8 ($n = 601$)		
	$\widehat{\beta}$	Wald χ^2	p	$\widehat{\beta}$	Wald χ^2	p
Thresholds						
[Y = 1]	−3.095	47.726	<0.001	−2.591	23.272	<0.001
[Y = 2]	−1.777	17.108	<0.001	−2.323	19.096	<0.001
[Y = 3]	−0.095	0.050	0.822	−0.264	0.260	0.610
Variables						
BAI	0.334	9.278	0.002	0.371	7.914	0.005
DEI	−0.001	14.439	<0.001			
INV	0.614	10.050	0.002			
SUB	−0.708	14.617	<0.001	−0.784	11.112	0.001
BAL	7.77×10^{-7}	15.208	<0.001			
L1	0.366	5.576	0.018	0.445	6.004	0.014
L2	0.505	1.597	0.206	0.554	1.266	0.261
INVINF				0.514	16.491	<0.001
BTU/SM				0.001	4.841	0.028
Mc Fadden pseudo R^2		0.044			0.041	
Pearson goodness of fit χ^2		1621.704	0.278		859.900	0.562
Test of parallel lines χ^2		15.305	0.358		17.471	0.133

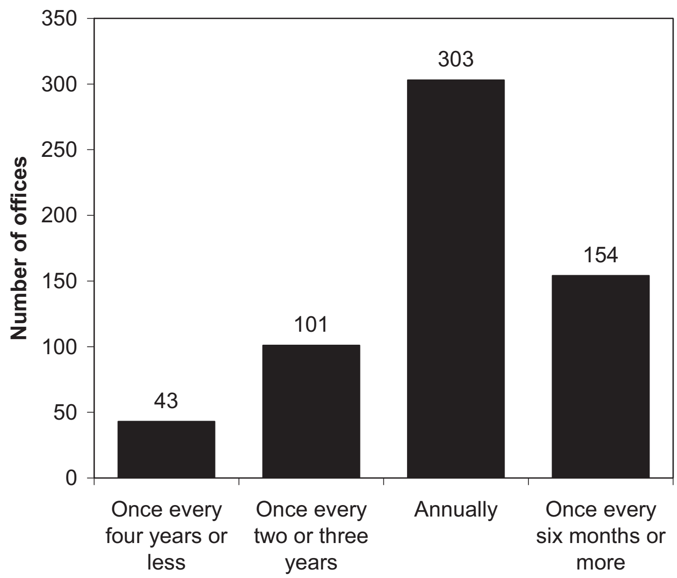

Fig. 7. The frequency of maintenance of the air conditioning units.

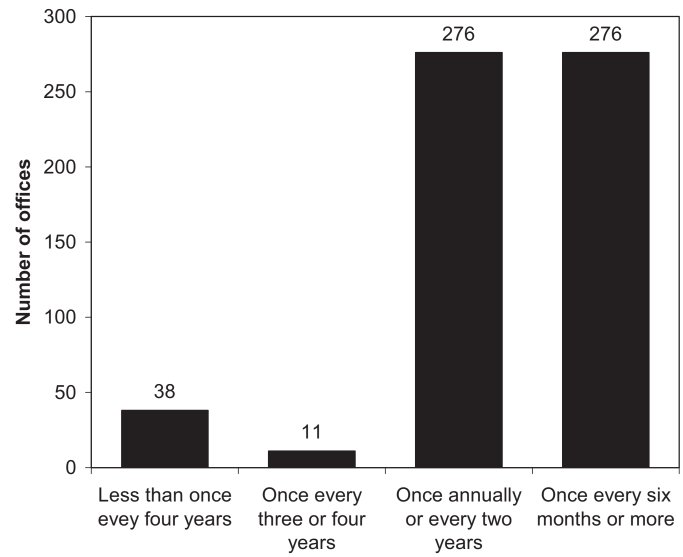

Fig. 8. Frequency of cleaning the filters of A/C.

replacement/installation more expensive compared to small offices. Those owning the office (PR) were more probable to be willing to install an inverter A/C ($\widehat{\beta} = 0.630$, $p = 0.002$), which is an expected result, in accordance with the findings of models Y_1, Y_2, and Y_3. Those that have installed their A/C for more years (ACY) were more probable to be willing to buy an inverter A/C on their next purchase ($\widehat{\beta} = 0.067$, $p = 0.002$), this is because they would have to replace them sooner compared to recent buyers of an A/C unit which did not have inverter technology. Those aware of inverter technology (INVINF) were more probable to be willing to install inverter A/C in the future ($\widehat{\beta} = 0.699$, $p < 0.001$) this is consistent with the previous model. Managers of older established companies (OLD) were less probable to be willing to install inverter technology on their next A/C purchase ($\widehat{\beta} = -0.030$, $p = 0.007$) compared to the younger ones. Those who claimed to be aware on energy saving (INFO) were more probable to be willing to buy inverter A/C on their next purchase compared to those who did not ($\widehat{\beta} = 0.514$, $p = 0.008$).

3.7. Frequency of air-condition maintenance and filter cleaning and willingness to have proper maintenance and filter cleaning

From those offices with A/C, 154 (25.6%) have them maintained by a technician twice a year and 303 (50.4%) once a year. On the other hand 101 (16.8%) have their A/C maintained once every 2–3 years and 43 (7.2%) have them maintained once every 4 years or less (Fig. 7).

Concerning filter cleaning of those offices which have A/C, 276(45.9%) do it every 6 months, 276 (45.9%) do it annually or once biannually. Only 11 (1.8%) do it once every 3–4 years and 38 (6.3%) less than once per 4 years (Fig. 8).

Results for model Y_7 are presented in the left hand panel of Table 9. The more affected a company by electricity shortages (BAI), the more probable to have the A/C units maintained frequently ($\widehat{\beta} = 0.334$, $p = 0.002$). The higher the cost of the electricity bill (DEI) the lower the probability of frequent maintenance of the A/C units ($\widehat{\beta} = -0.001$, $p < 0.001$). Those companies having A/C with inverter technology (INV) were undertaking more frequently maintenance of their A/C units ($\widehat{\beta} = 0.614$, $p = 0.002$). Those companies whose main activity was services (SUB) were less probable to undertake maintenance of their A/C units frequently ($\widehat{\beta} = -0.708$, $p < 0.001$) compared to those whose main activity was trading. This is an expected finding because offices dealing with trade have more frequent contacts with more customers and they are keen to provide an attractive atmosphere with appropriate temperature and ventilation levels. Furthermore, in commercial companies', doors open more frequently because of incoming and outgoing customers, resulting in high thermal loads (due to losses), thus there is need for more frequent maintenance. Those companies with a higher turnover (BAL) were more probable to undertake maintenance of their A/C units more frequently ($\widehat{\beta} = 7.77 \times 10^{-7}$, $p < 0.001$). One explanation is that they can afford to pay for it. In the case of large companies, they have their own technical groups that can undertake more frequently maintenance of the A/C units, and/or have been installed large units which require less effort to maintain (e.g. easier to maintain one large unit compared to two small ones). Private companies (L1) were more probable to undertake maintenance often compared to limited liability companies ($\widehat{\beta} = 0.366$, $p = 0.018$), which is consistent with findings from models discussed in the previous sections.

Results for model Y_8 are presented in the right hand panel of Table 9. Managers from companies affected by electricity shortages (BAI) were more probable to clean the A/C filter frequently ($\widehat{\beta} = 0.371$, $p = 0.005$), which is an expected finding. Those informed about inverter technology (INVINF) were more probable to clean the A/C filter frequently ($\widehat{\beta} = 0.514$, $p < 0.001$), which is also an expected finding as these respondents are energy aware. Offices dealing with services (SUB), were more probable to clean the A/C filter less frequently ($\widehat{\beta} = -0.784$, $p = 0.001$), compared to offices that deal with trade. This is consistent with the results of model Y_7. The higher the ratio of the total BTU to the total office surface (BTU/SM) is the more probable it was for the A/C filter to be cleaned frequently ($\widehat{\beta} = 0.001$, $p = 0.028$). This means that the managers of offices with high A/C intensity do it more frequently. Private companies (L1) were more probable to clean their A/C filters frequently, compared to limited liability companies ($\widehat{\beta} = 0.445$, $p = 0.014$) which is similar to previous model.

Fig. 7 shows that 457 (76%) of the respondents have had their A/C maintained regularly, i.e. at least once per year. About half of the rest (73 out of 144) stated that they were willing to do so in the future, after the information session (Fig. 9). Fig. 8 shows that 276 (45.9%) of the respondents regularly clean their A/C filters; i.e. at least twice per year. From the remainder only 49 (15.1%) stated that they would do so after the information session (Fig. 9). This shows that managers were not convinced that providing money

Table 10
Results for models Y_9 and Y_{10}.

Variables and statistics	Model Y_9 ($n = 144$)			Model Y_{10} ($n = 325$)		
	$\widehat{\beta}$	Wald χ^2	p	$\widehat{\beta}$	Wald χ^2	p
C	0.215	0.020	0.889	−0.764	17.408	<0.001
INV	−1.571	6.480	0.011			
ACY	0.060	5.682	0.017			
SUB	0.787	4.167	0.041			
LN (BTU/SM)	−0.585	5.329	0.021			
DEI/BAL	0.458	6.436	0.011			
PER				0.128	6.460	0.011
DEI				−0.004	7.324	0.007
Pseudo R^2		0.176			0.041	
−2 LL		17.474			360.217	
Hosmer and Lemeshow test		5.022	0.755		6.228	0.622
Overall predictive accuracy		98.6%			74.2%	

and time resources for extra A/C filter cleaning was worth it. As a general conclusion, though, the above figures show that managers were receptive to information about environmental, economic and health benefits derived from the regular maintenance of the A/C but there is still place for specific information about the cleaning of filters.

Results for model Y_9 are presented in the left hand panel of Table 10. The older the A/C (ACY) the more probable the manager to be willing to undertake the regular maintenance ($\widehat{\beta} = 0.060$, $p = 0.017$). Managers from offices with A/C equipped with inverter technology (INV) were less probable to be willing to undertake proper maintenance ($\widehat{\beta} = -1.571$, $p = 0.011$). This estimator has the opposite sign from model Y_7, this is an indication that the information session had a more positive impact on those running a company with conventional A/C and implies that those "remaining" inverter possessors over-trust inverter technology. Managers running companies dealing with services (SUB) were more probable to be willing to undertake proper maintenance if they did not do it already ($\widehat{\beta} = 0.787$, $p = 0.041$) compared to those dealing with trade. This means that they were more receptive to the information session provided. It was found that in offices with low values of the natural logarithm ratio [total installed BTU]/[square meter of the office] (BTU/SM) it was less probable to be willing to undertake regular A/C maintenance ($\widehat{\beta} = -0.585$, $p = 0.021$). This means that the "remaining" high cooling intensive offices were less receptive to the information session provided. Finally, it was found that managers of offices with high values of the ratio [electricity bill]/[turnover] (DEI/BAL) were more probable to undertake regular A/C maintenance in the future, after the information session ($\widehat{\beta} = 0.458$, $p = 0.011$), which mainly means that the high energy intensive offices, were more receptive to the information provided.

Results for model Y_{10} are presented in the right hand panel of Table 10. Managers of companies with high number of employees (PER) were more probable to state that they would regularly clean their A/C filters ($\widehat{\beta} = 0.128$, $p = 0.011$) which is rational since it would be beneficial to more people and also in such companies they may have organized technical services and therefore it would be easier to run additional A/C cleaning. In companies that pay high electricity bills (DEI) and not having biannual A/C filter cleaning, their managers were less probable to be persuaded after the information session to run regular A/C filter cleaning ($\widehat{\beta} = -0.004$, $p = 0.007$). This indicates that managers from those companies underestimated this activity anyway and were not persuaded by the energy saving benefits of this practice.

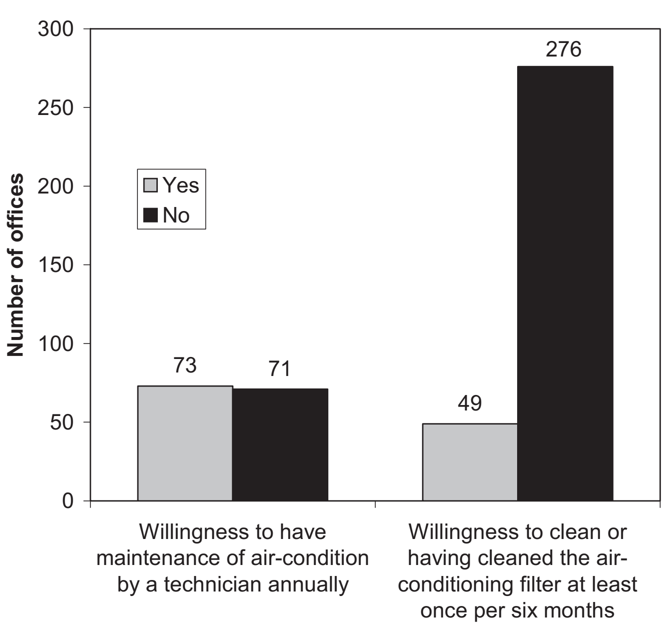

Fig. 9. Willingness to undertake annual maintenance of the air-condition with a technician and filter cleaning twice a year if not done already.

4. Conclusions

Energy saving, rational energy use and energy efficiency technologies and behaviors in office buildings have to be promoted and sustained by a combination of policies and incentives. Despite the fact that the island of Crete is a southern area with short and mild winter the energy efficiency in heating and air-conditioning is rather low. Installation of double glazing windows has become a standard practice in the last 10 years since 53.6% of the office buildings have installed them. Although awareness concerning the annual service of the boiler-burner seems very high (95.33%) the awareness concerning energy saving through the use of radiator thermostatic valves is relatively low. In general, it was illustrated that the more informed a manager is about energy related issues; the more probable he/she is to make energy wise purchasing decisions but there is still room for improvements through energy awareness.

Heating and cooling with air-conditioning units, is, by far (87.2%) the predominant mode in office buildings. Air conditioning units are mainly used for cooling during the summer period, seriously contributing to the high summer electricity peak of the autonomous insular electricity system of Crete, which is not connected to the mainland.

Inverter technology of air-conditioning split units has not, so far, been widely implemented. Only 9.8% of the offices were using it, but 44.2% of those who had not installed it stated their willingness

to do so on their next purchase. The findings related to the variables which affect the willingness to install A/C inverter technology show that the short awareness – information session, provided by the researcher, is not enough to fully demonstrate the advantages of this technology. The remarkable success of the program of the Greek Ministry of Development for the promotion and replacement of A/C units with high energy class inverter air-conditioning units proves the necessity of the implementation of similar subsidy initiatives.

The offices dealing with trade (which actually means more incoming customers) undertake more frequently the service of their A/C units, due to the need to keep a comfortable indoor environment of the firm. Owners are keen to provide an attractive atmosphere with appropriate temperature and ventilation levels. Furthermore, in commercial companies, there is more thermal load thus the need for more frequent maintenance, since doors open more frequently because of incoming and outgoing customers. It was found that larger companies were more probable to undertake regular maintenance which suggests that large units, which require less effort to maintain, could have been installed. An effective policy regarding maintenance should focus on small companies and companies that deal with services.

Older people take more energy wise decisions which is explained by the idiosigracy of older people in Greece. 35–45 years ago electricity had not been installed in all towns and villages. At this period, electricity was a new and probably an expensive commodity, since the standard of living was not very high and many people were still at that time trying to get basic amenities. So, even today older people appeared to appreciate and to be more sensitive to electricity provision behaving in a more “energy wise” way than younger people.

Policies promoting the ownership of office spaces will also be positive for energy efficiency, as the owners are more likely to make basic energy efficiency investments especially for the building envelope (double glazing windows, roof and wall insulation, etc.). Energy labeling, in general, and especially for A/C units – has to be promoted by the sellers of goods, and by technicians and engineers who install them. Local authorities have to perform controls on whether the compulsory information of energy labeling for clients, chambers of industry, trade, engineers, etc., is adequately provided by the sellers. An integrated strategy to reduce cooling demand in office buildings should focus on the construction of exemplarily energy buildings, where efficient and innovative energy technologies would be demonstrated in order to persuade energy users and investors.

Therefore the results of the research concerning the use of heating and air conditioning technologies, the relevant awareness levels and the willingness to pay for integration of more energy efficient technologies, can be an important part of the basic principles for planning and implementing energy awareness campaigns and targeted interventions concerning the promotion and use of more energy efficient technologies. Follow up research should focus on consumer satisfaction, and more specifically on the effects on the working environment and thermal comfort users from the improved heating and cooling technology. Commercial Chambers and Associations could strongly promote energy labeling and inverter A/C units technology by the sellers and commercial firms. Chambers of Engineers and Technical Associations have to promote training in maintenance and in use of efficient heating and A/C technologies. Energy Agencies and Local/Regional Authorities have to plan and coordinate energy efficiency awareness campaigns for the general public, as well as, targeted interventions for office buildings, taking into account the specific socio-cultural profile of the “targeted audience”. These measures can be adequately combined with and/or integrated in a generic building energy efficiency planning and implementation framework which promotes simultaneously the 2002/91/EC European Directive on Energy Performance of Buildings [30] and the achievement of 20% energy saving and 20% Green House Gases reduction by 2020, in the European Union.

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